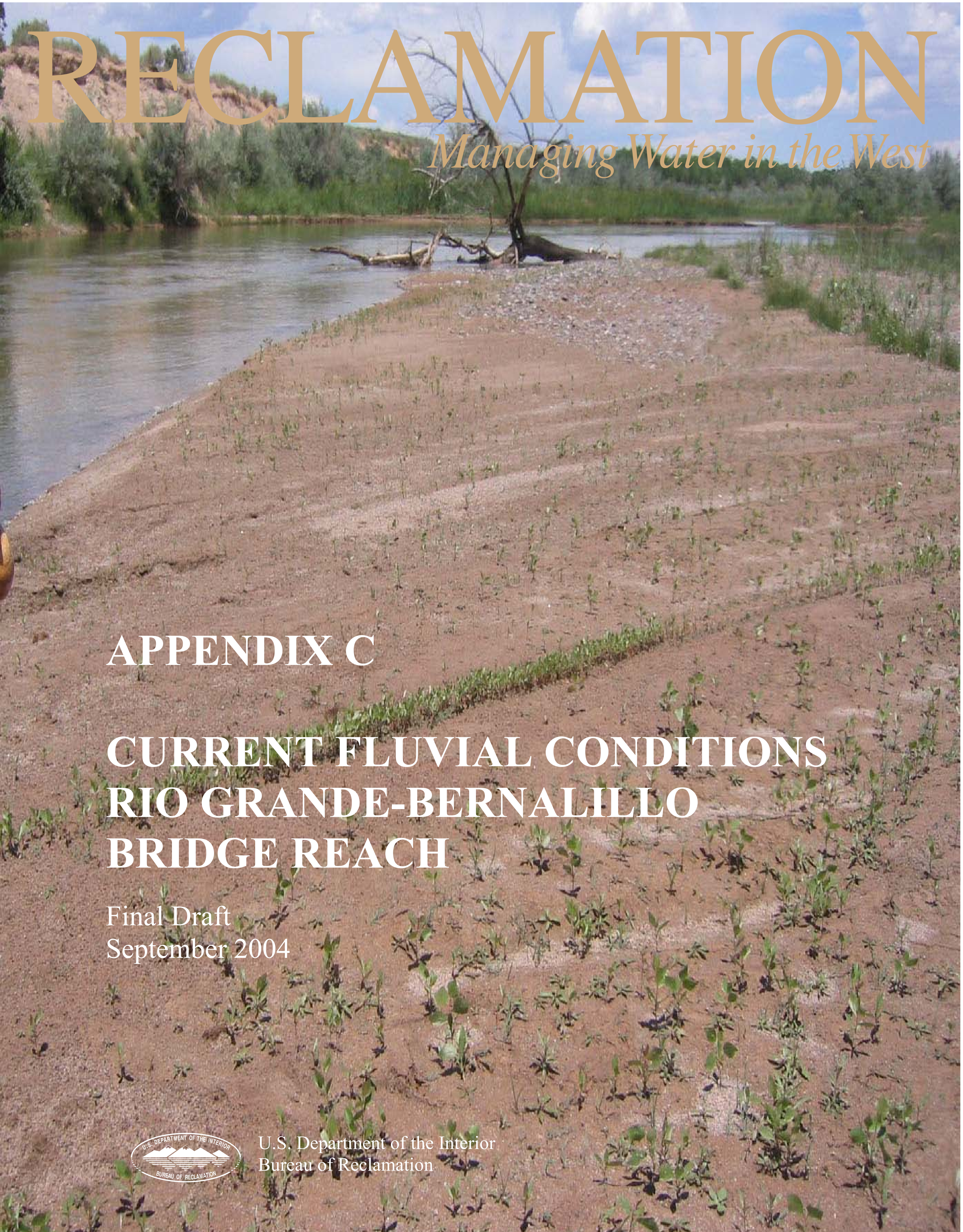

RECLAMATION
Managing Water in the West

APPENDIX C

CURRENT FLUVIAL CONDITIONS RIO GRANDE-BERNALILLO BRIDGE REACH

Final Draft
September 2004

U.S. Department of the Interior
Bureau of Reclamation

APPENDIX C

CURRENT FLUVIAL CONDITIONS
Rio Grande – Bernalillo Bridge Reach

September 21, 2004

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EXECUTIVE SUMMARY

The Bernalillo Bridge reach of the Rio Grande extends downstream from the NM Hwy 550 bridge crossing in Bernalillo to just downstream of the Rio Ranch Waste Water Treatment Plant at the Arroyo de las Montoyas/Harvey Jones Outfall confluence: a reach of approximately 5.3 miles in river length. This section of the Rio Grande flows along the Rio Grande Rift zone in which thousands of feet of fluvial sediments have been deposited in the river valley. The last major flood event occurred in 1941-42. Although river gage data indicates that most of the flood water came from upstream of Cochiti, NM, the highest yearly precipitation on record at the Albuquerque Airport climate gage also occurred in 1941. At present, the yearly average precipitation is 10.5 in/yr at Corrales (1984-1999), while the long term average precipitation at the Bernalillo/Corrales gages is 9.1 in/yr (1948-1999). Prior to 1973, the 2-year recurring peak flow was just over 10,000 cfs, however post-1973 data indicates a current peak flow of under 6,000 cfs. In fact, no flows greater than 10,000 cfs have passed San Felipe since 1967. The amount of measured suspended sediment for the reach has decreased greatly since data collection began in 1956 (USGS Rio Grande gage at Albuquerque). Channelization work dates back to the 1930s, when the initial ‘floodway’ was constructed. Most of the 1950s riverine work consisted of additional channel straightening and jetty jack construction. Generally, this channel has been a wide, shallow, and sand-bedded channel with a braided morphology, however in recent years it has changed toward a gravel bed with a meandering morphology.

Sub-reach 1 which extends approximately 2 miles downstream from the NM Hwy 550 bridge has already converted from the sand bed, braided morphology to a gravel bed, single-threaded morphology. At high flows, several high flow channels become wetted, creating an island-braided morphology. The low flow characteristics include a slightly meandering, deep thalweg. The size of bed material is gravel/cobble with only occasional sand deposits in the main channel. Sand is being stored in the high flow channels and banks. Sediment transport of the larger bed material begins near the channel forming flow, indicating the gravel bed is relatively stable. High flow channels and abandoned bars/islands are numerous in this sub-reach.

The next ¾ mile downstream, sub-reach 2a, is similar in form and character to sub-reach 1. Sub-reach 2a is a single-threaded, deep channel at low flows with less evidence of a meandering thalweg. Also, islands and abandoned bars are not as numerous as sub-reach 1. The channel bed is gravel/cobble with occasional sand deposition: the gravel moves during channel forming or greater flows indicating a stable bed.

Sub-reach 2b (about 1 mile in length) appears to be an upstream depositional zone for Arroyo de la Barranca. The channel form is more of a braided form with a slightly wider channel at low flows than sub-reach 2a. The main feature that differs in this sub-reach from the upstream channel is a smaller bed material size. The bed material in sub-reach 2b consists of small gravel and sand, which is easily transported. Bar and island formation is limited in this sub-reach.

Sub-reach 3 (1.5 miles in length) is currently in transition from the low-flow braided morphology to a slightly meandering thalweg/single-threaded channel pattern with gravel. The channel morphology can not be clearly described as braided, single-threaded or meandering. Although a relatively deeper thalweg is present in this section, the flow spreads out across the whole active channel. Sections of the channel are dominated by gravel, while others are sand

bedded. The gravel is likely transported only at higher flows, while the sand material is mobile at most flows. Islands are present in this reach, however, they are not as numerous as in sub-reach 1.

The future conditions of the entire reach include a coarsening of the channel bed, especially in those locations that currently have sand or small gravel material. These same locations are expected to incise until the gravel size present on the bed forms an armor layer that is less mobile. The channel pattern is expected to continue evolving towards a single-threaded flow with a slightly meandering thalweg. The high flow channels in sub-reaches 1 and 2a will become more abandoned, and likely completely abandoned as the channel bed continues to degrade. Those channels with a slightly meandering pattern and point bar development are expected to continue to evolve towards a fully meandering pattern, potentially becoming a pool-riffle morphology, as riffles have already begun to form. The channels that do not currently exhibit a meandering pattern are expected to convert as well.

1.0 INTRODUCTION AND HISTORY OF REACH

The Bernalillo Bridge reach, is located within the most populated reach of the Middle Rio Grande: the Albuquerque reach (Figure 1). As a consequence, this section of river is continuously monitored by many federal, state, and city agencies as well as private organizations and the general public. Due to public safety, this reach of the Rio Grande has also been extensively managed. Although human needs have dominated the management decisions along this section of the Rio Grande, recent listing of the Rio Grande silvery minnow and the southwestern willow flycatcher as endangered species in the 1990s has heightened the need to include wildlife needs in resource management decisions. The new challenge for decision makers is to produce management strategies that are beneficial to both humans and the wildlife. In making these decisions, managers need to both learn from historic river management actions and understand the current evolution of the Rio Grande.

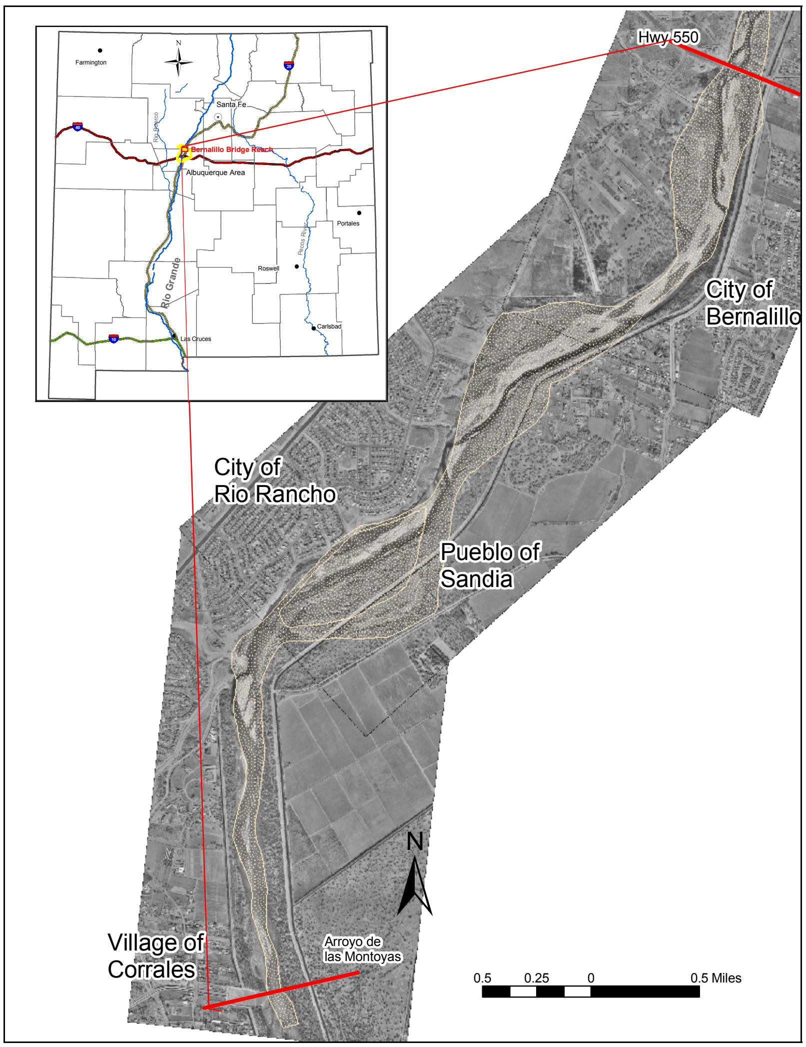

Figure 1: Location of the Bernalillo Bridge reach of the Rio Grande, NM overlain on a contour/topographic map (left), and the 2001 aerial photos of the reach (right) with an estimated location of the Rio Grande from digitized USGS 1918 topographic quadrangles produced by Reclamation's GIS and Remote Sensing Group in the Technical Services Center, Denver CO.

The Bernalillo Bridge Reach (Figure 1) of the Rio Grande extends from the bridge crossing of NM Highway 550 at Bernalillo downstream to the Harvey Jones outfall on the Arroyo de las Montoyas (5.5 miles/9 km). The purpose of this study is to determine current channel conditions of the Rio Grande and to predict the future sediment and channel morphology under the current management regime.

1.1 Review of Geologic History of the Reach/Area

Two geologic processes influence the geomorphic evolution of this reach of the Middle Rio Grande valley: extensional faulting that is mostly parallel to the valley, a.k.a. the Rio Grande rifting (Chapin 1988), and valley filling from both the ancestral and current Rio Grande (Hawley 1978). Extensional faulting, associated with the Rio Grande rifting has created a north-south extending valley, in which the Rio Grande valley subsides relative to the sides of the rift which are uplifting and creating mountains. The rifting began about 25-30 million years ago and continues to present day. It created a deep valley, partially filled by debris (sediment) which originates from both upstream and local tributary sediment sources. Several thousand feet of sediment (Hawley 1978) overlie the sinking bedrock in the study area.

1.2 Precipitation Patterns

Combining data from two climate gages, Bernalillo and Corrales climate gages (Hydrosphere 2000), create a nearly continuous precipitation record (1948-2000). Data was collected at the Bernalillo gage from 1948-1982 (elevation of 5,060 ft). The Corrales gage began collecting data in 1983, and continues to date (elevation of 5,015 ft). Climate patterns dating back to the 1930's are available south of the study site at the Albuquerque airport (ALB-airport) climate gage (elevation of 5,310 ft). Although the Bernalillo and Corrales climate gages are very close to the study area, the ALB-airport data is more extensive thus this gage data is also presented (Figure 2). The ALB-airport gage generally received less precipitation than either the Bernalillo or Corrales gages, however, the general precipitation patterns are similar between all the gages. Three distinct precipitation patterns emerge since the 1940s (Figure 2 and Table 1): 1) low precipitation (1942-1956) which is commonly referred to as the 1950s drought; 2) moderate precipitation (1957-1979); and 3) above average precipitation after 1979. Although the precipitation was above average after 1979, several years of below average rain fall also occurred in this period (Figure 2).

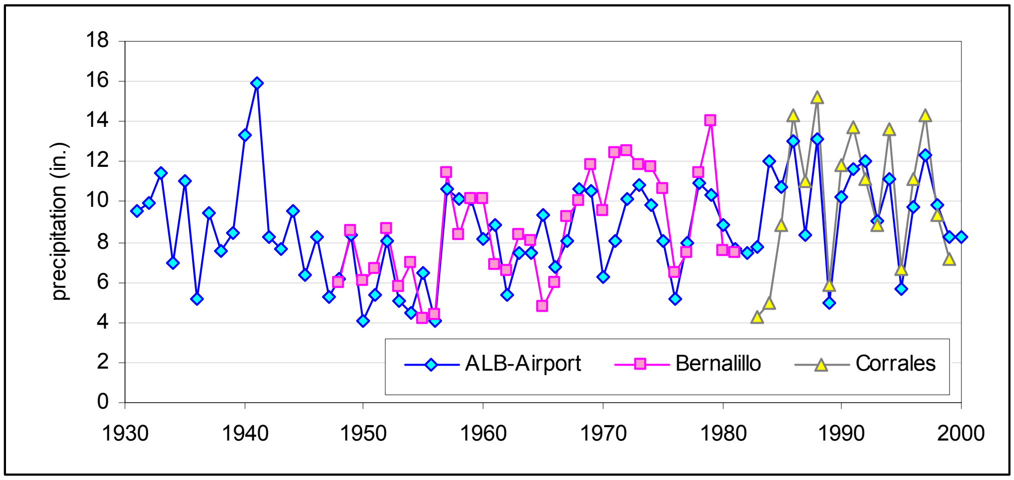

Figure 2: Yearly precipitation totals for the Albuquerque Area. Raw climate data supplied by Hydrosphere, 2000.

Table 1: Average yearly precipitation values for the Albuquerque Area. Raw climate data supplied by Hydrosphere, 2000.

	ALB-Airport	Bernalillo	Corrales	Bernalillo-Corrales
Yearly Average (whole record)	8.71	8.59	10.15	9.11
1942-1956	6.49	6.37	n/d	-
1957-1979	8.51	9.50	n/d	-
1984-1999	10.14	n/d	10.52	-

Although precipitation falls each month, the majority of the precipitation falls July-September (Figure 3). A cursory review of the daily records indicates that during the July-September period, storm events on individual days often supplied the recorded months' average precipitation.

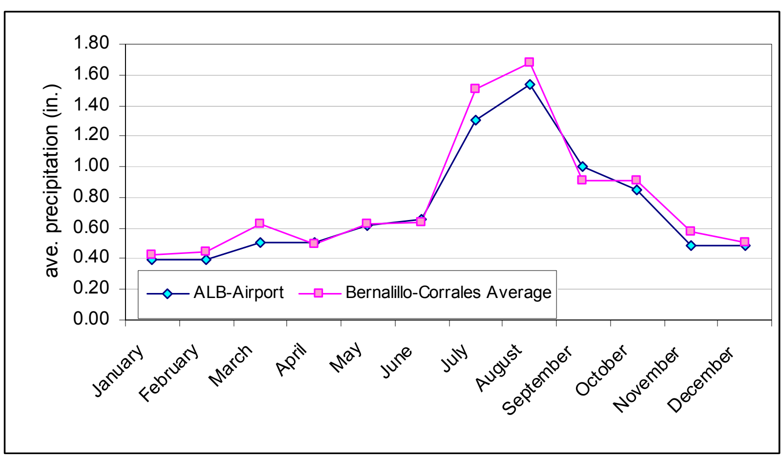

Figure 3: Average monthly precipitation totals for the Albuquerque Area. Raw climate data supplied by Hydrosphere, 2000.

1.3 Monumental Historic Water and Sediment Events

Based on a summary prepared by Scurlock (1998), nearly 60 floods were recorded in the Middle Rio Grande area (Velarde to Elephant Butte), 1822-1942. Of these 60 floods, 7 of the floods were described as very large or valley-filling type events. The very large events were estimated to be greater than 100,000 cfs. The latest floods described by Scurlock (1998) were back-to-back high flows in 1941 and 1942. U.S. Geological Survey (USGS) river gage data indicate peaks near 20,000 cfs for each of these flows at San Felipe (Figure 4), with the 1941 peak at almost 23,000 cfs. Only two flows have exceeded 12,000 cfs since 1942. No flows greater than 10,000 cfs have passed San Felipe since 1967 (Figure 4).

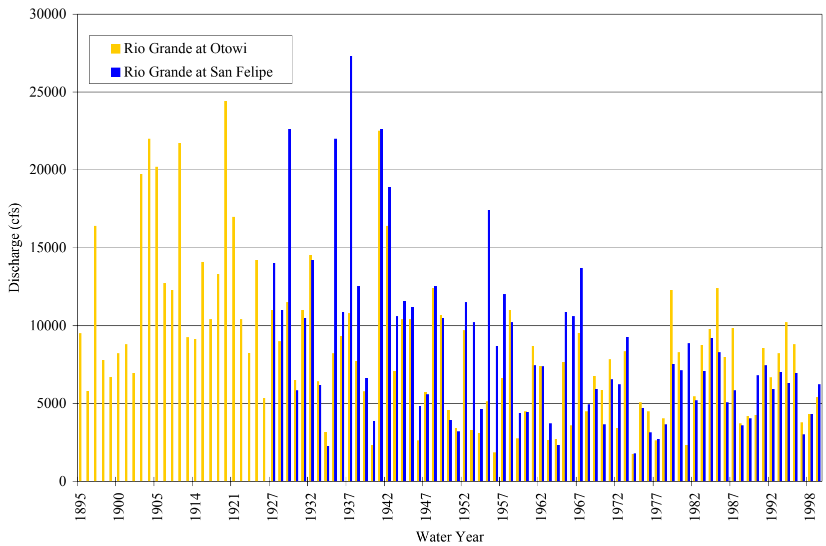

Figure 4: Peak discharge records for USGS Rio Grande gage data at Otowi Bridge (1895-1999) and San Felipe (1927-1999).

Although flows in 1941 and 1942 were large and extensive (throughout the Middle Rio Grande valley), according to peak discharge data, the largest recorded instantaneous discharge was on June 26, 1937 (Figure 5), at just over 27,000 cfs (12,000 cfs mean daily discharge) for the USGS Rio Grande gage at San Felipe. Based on the hydrograph data (Figures 4 & 5), this flow was a summer thunderstorm event generated downstream of the Otowi gage. As typical with summer storm floods, this flow peaked and diminished quickly (Figure 5).

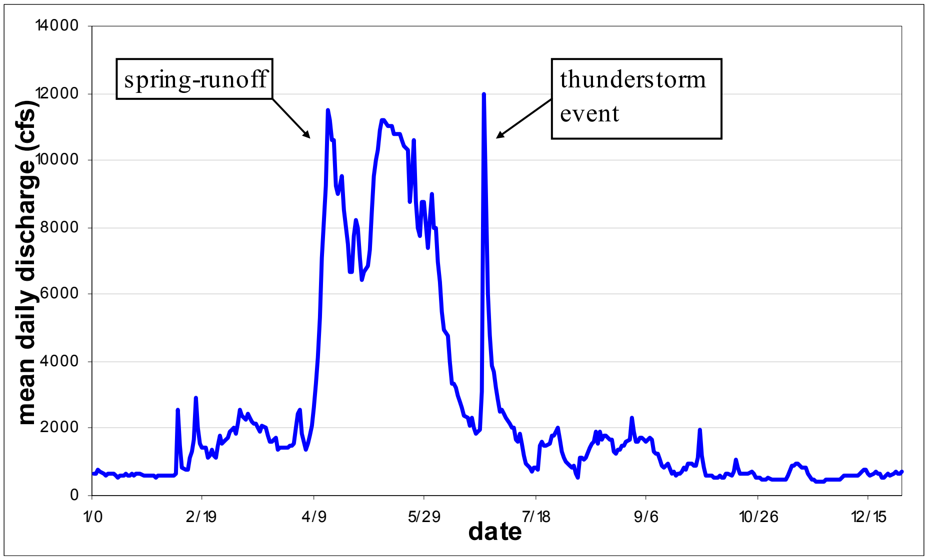

Figure 5: Mean daily discharge for 1937; USGS Rio Grande gage at San Felipe.

Suspended sediment data from the combination of two USGS river gages shows that the amount of suspended sediment decreased dramatically after 1958 (Table 2). The full cause of this change in sediment supply is not clear but is likely associated with both a changing climate and management of the entire watershed. Another decrease in the supply of sediment occurred in 1973, which was the year that the Cochiti dam began operations and storing the upstream supply of sediment in the reservoir. A temporary increase in suspended sediment occurred between 1993 and 1995; reviews of the precipitation record during 1993-1995 indicate that 1994 had an extensive thunderstorm season (May through October) and a higher than average yearly precipitation amount, over 13 inches (Hydrosphere 2000). The higher than usual thunderstorm activity likely created the relative increase in sediment supply to the Rio Grande (USBR 2003). After the temporary pulse in 1993-1995, the measured suspended sediment amounts returned to levels similar to 1973-1993.

Table 2: Average yearly amount of suspended sediment collected at the USGS Rio Grande gages at Albuquerque and Bernalillo, NM.

Time Period	Average Suspended Sediment (million tons/yr)
1956-1958	10.8
1958-1972	3.0
1972-1973	7.6
1973-1985	1.2
1985-1993	0.3
(1989-1992)	(no data collected)
1993-1995	2.8
1995-1999	0.8

1.4 History of Channelization

Historically, the Middle Rio Grande was a relatively straight, braided and aggrading channel (Dunne and Leopold 1978, Lagasse 1980, Leopold 1994, Leopold et al. 1964, USBR 2003). During the rehabilitation of the Rio Grande for mostly irrigation purposes, the Middle Rio Grande Conservancy District constructed a floodway through this reach during the 1930 to 1936 period (Woodson and Martin 1962). Comparing the 1918 maps with the 1935 photos (Figure 6), the most significant changes from the floodway construction appear to be an overall narrowing of the channel, while the general location of the river did not change significantly. Several bends were abandoned as well as existing side channels. An initial levee system was also constructed during this time period. By the 1950's, the Rio Grande occupied a wide shallow channel between the levees of the floodway which had little to no bank development (Dunne and Leopold 1978, and Leopold 1994). The average level of the channel bed, especially in the Albuquerque area, was above the elevation of the floodplain located outside of the levees (Woodson and Martin 1962). Continued flooding outside the levees and levee breaches prompted the U.S. Congress in 1948 and 1950 to authorize additional river modifications to control sedimentation and flooding along the Rio Grande. As part of this authorization, the Rio Grande was re-channelized, Keller jetty fields were placed along the floodway to control sedimentation, and an improved levee system was built. Since the river-work in the 1950's, the study reach appears stable in terms of locations (Figure 6), however, mid-channel bars began stabilizing in the 1980's, that vegetated in the early 1990's. These vegetated bars are now stable islands.

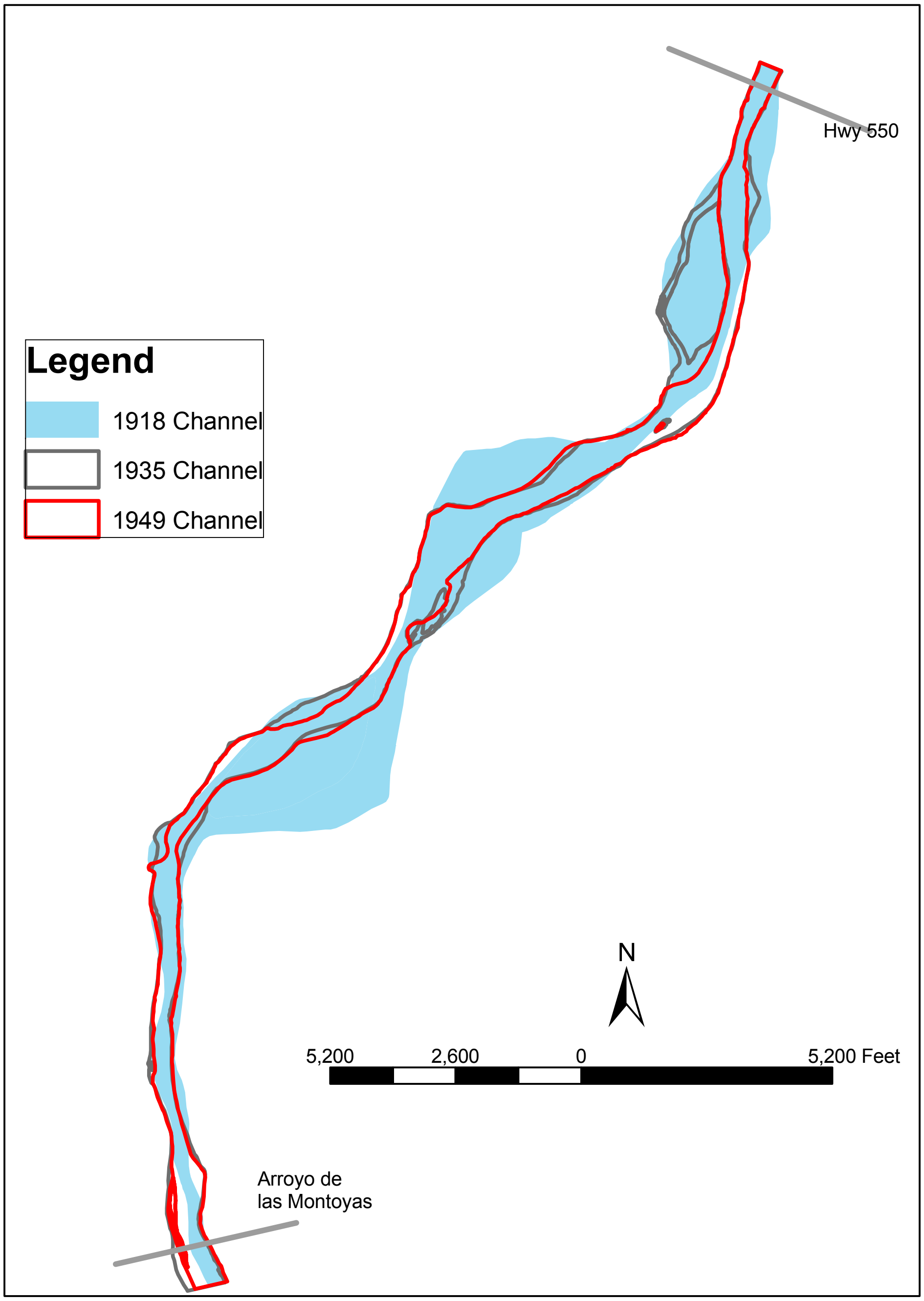

Figure 6a: Non-vegetated active channel of the Rio Grande, Bernalillo Reach; 1918, 1935, and 1949 channels. Modified data: digitized Rio Grande channel and river features from aerial photography, produced by the Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

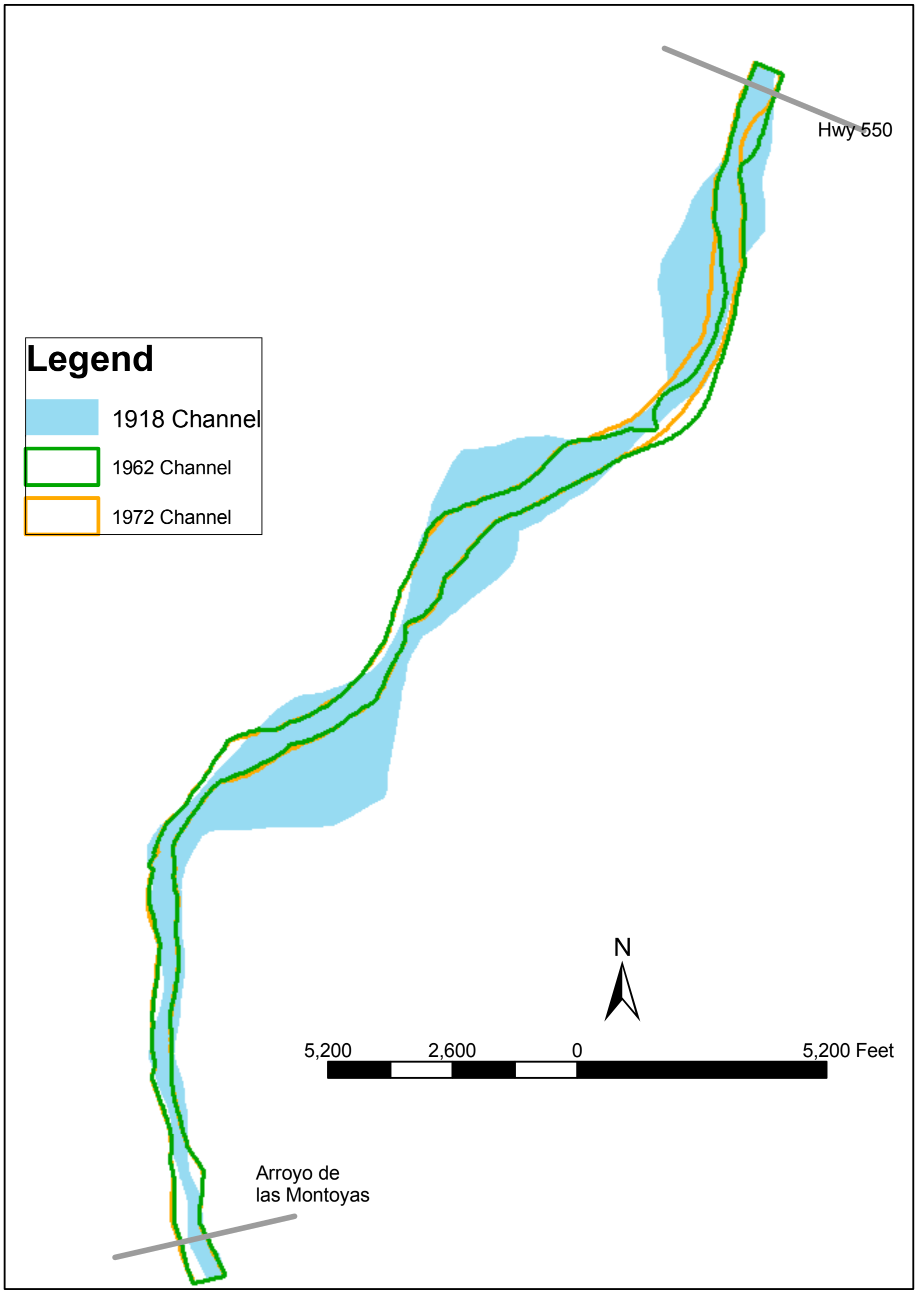

Figure 6b: Non-vegetated active channel of the Rio Grande, Bernalillo Reach; 1918, 1962, and 1972 channels. Modified data: digitized Rio Grande channel and river features from aerial photography, produced by the Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

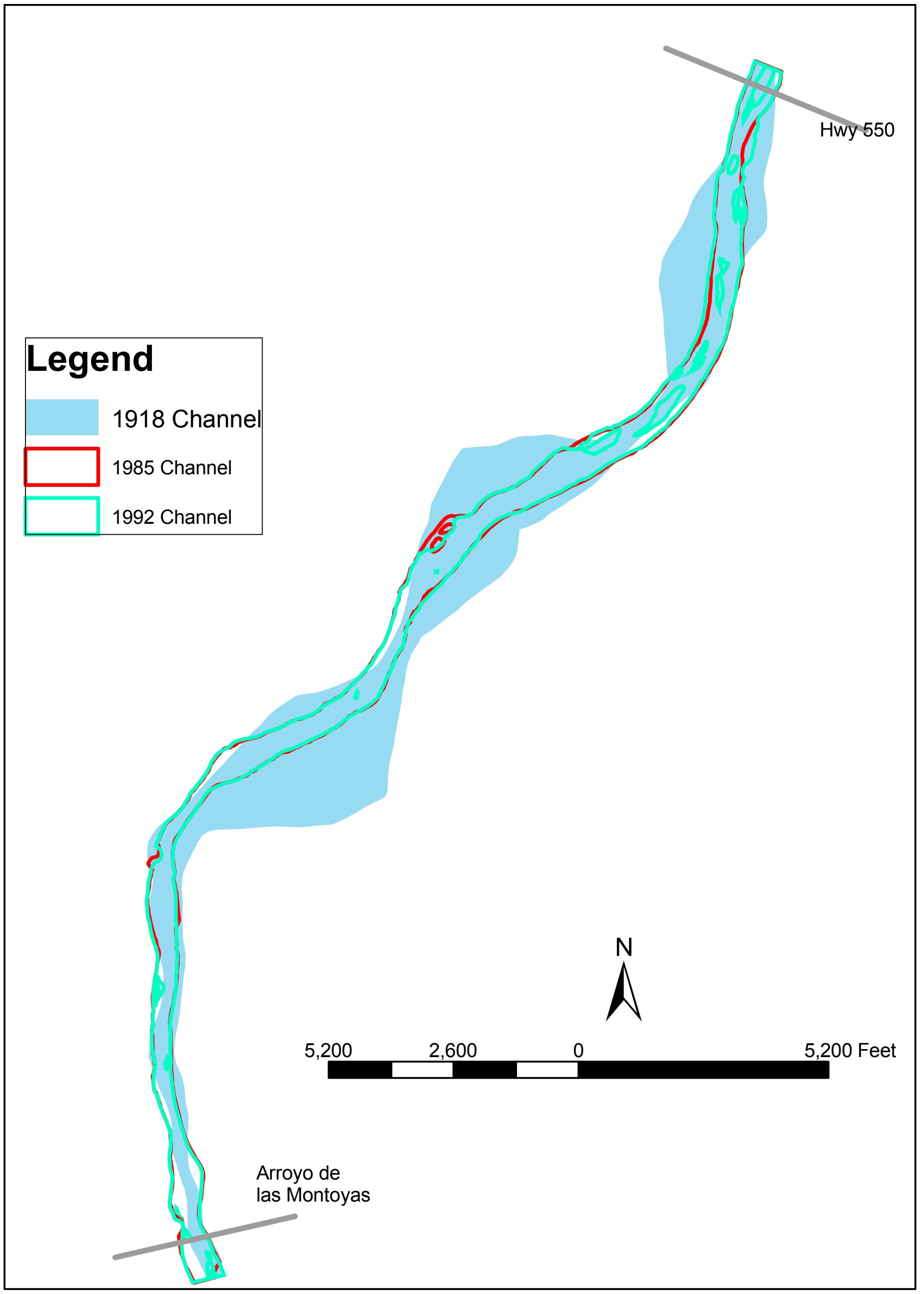

Figure 6c: Non-vegetated active channel of the Rio Grande, Bernalillo Reach; 1918, 1985, and 1992 channels. Modified data: digitized Rio Grande channel and river features from aerial photography, produced by the Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

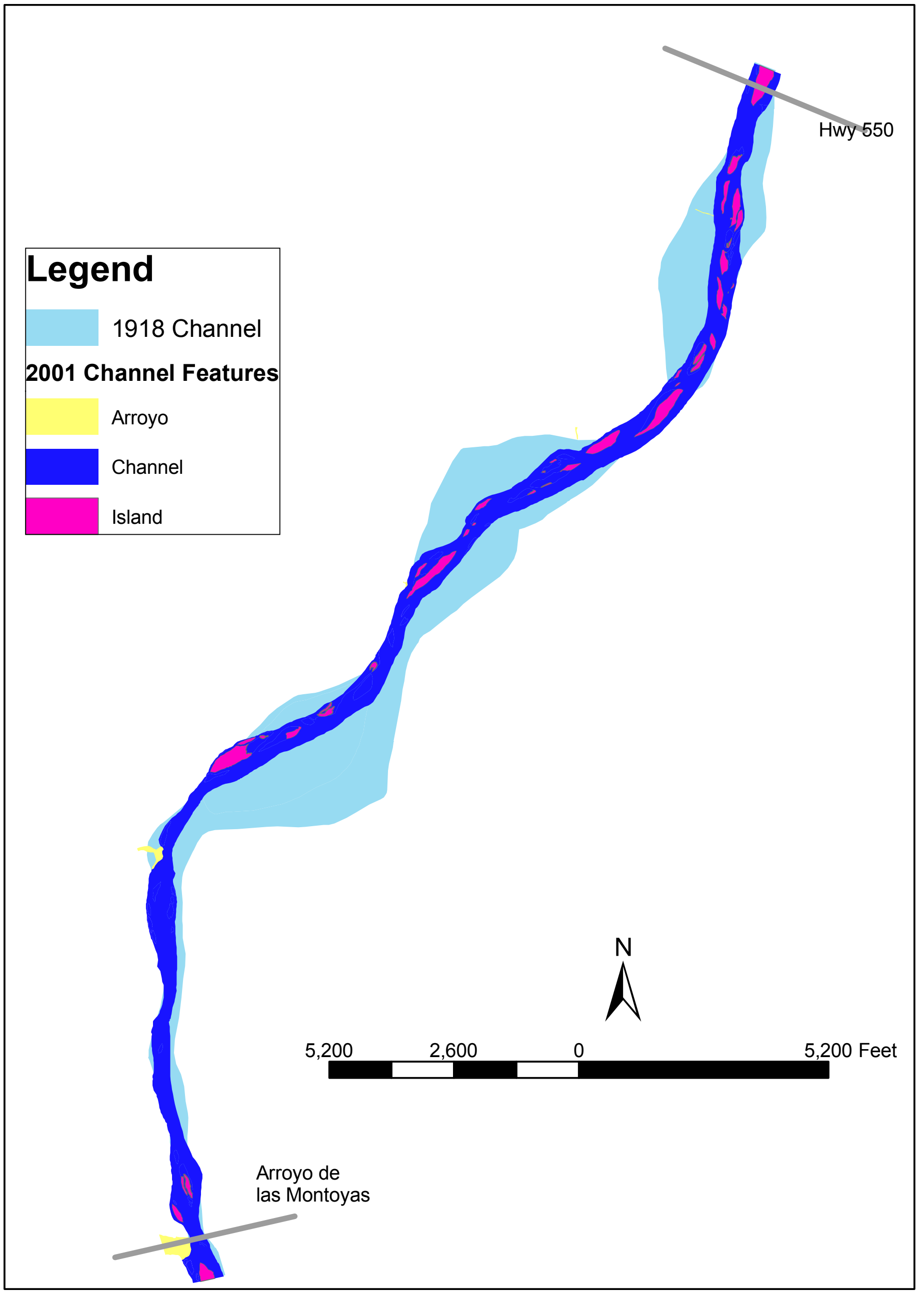

Figure 6d: Non-vegetated active channel of the Rio Grande, Bernalillo Reach; 1918 and 2001 channels. Modified data: digitized Rio Grande channel and river features from aerial photography, produced by the Reclamation, Technical Services Center-GIS and Remote Sensing Group, Denver, CO.

2.0 CURRENT CONDITIONS

The current conditions assessment includes: channel forming flow discussion; a delineation of the reach into 3 sub-reaches and a description of each; a discussion of the larger bed material sizes present (2001); and potential sediment mobility. The physical channel descriptions were observed in both the summer and winter months of 2000. Cross section and bed material data were collected by government contractor in the spring of 2001 along each range line present in the reach (Figure 7). The hydraulic parameters of these cross sections are determined using the US Army Corp of Engineer's HEC-RAS v. 3.0 (USACE, 2001) 1-dimensional, backwater model. A channel forming flow of 5,000 cfs was used in the model. The HEC-RAS output for each cross section was averaged for each sub-reach by weighting each cross section value by its representative channel length.

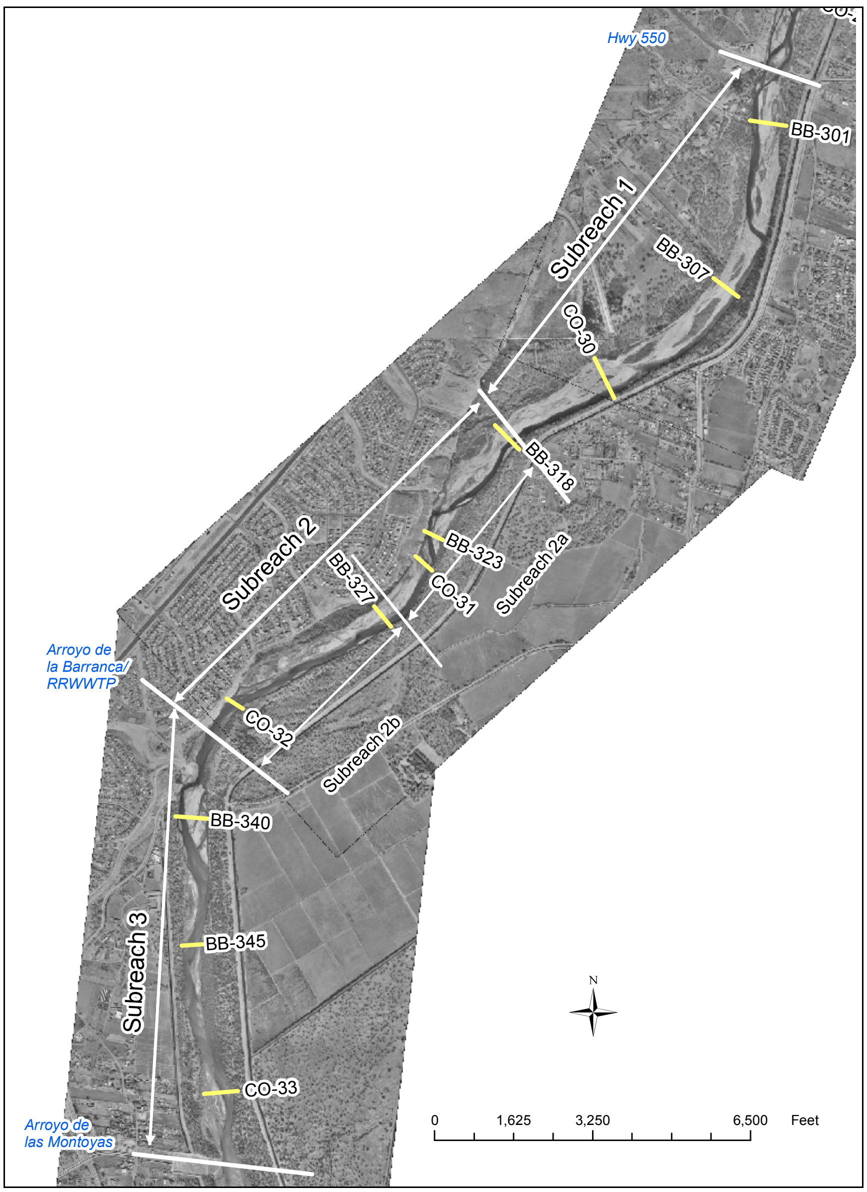

Figure 7: Reach map displaying location of range lines and sub-reach boundaries for the Rio Grande, Bernalillo Bridge Reach, overlain on 2001 aerial photography.

2.1 Channel forming flows

As defined by Knighton (1998), the flow that occurs approximately every 1.5-2 years is usually considered the channel forming flow. Unfortunately, no gage is currently located within the Bernalillo Bridge reach, and the closest gage (USGS Rio Grande gage at Albuquerque) has a short record (1942-2001). However, the USGS gage upstream, Rio Grande at San Felipe, which is approximately 11 miles north of Bernalillo has a continuous peak discharge record dating back to 1927. After separating the data for pre- and post-Cochiti Dam (1973 water year), a simple flood frequency curve (Figure 8) was developed to assess the channel forming flow with a 1.5-2 year recurrence interval. Prior to the closing of Cochiti dam, the gage at San Felipe received flows greater than 10,000 cfs approximately every 2 years. After flow modifications began at Cochiti dam (post-1973), the channel forming flow is estimated between 5,000-6,000 cfs.

These post-Cochiti dam channel forming flow values are consistent with estimated 2-year recurrence values found in other studies. Bullard & Lane (1993) reported that for the USGS Rio Grande gage at San Felipe the 2-year recurrence flows was 5,600. Richard (2001) reported a 2-year flow estimate for the USGS Rio Grande gages at Otowi and Cochiti at just over 5,100 cfs. The channel forming discharge at the San Acacia gage, located downstream of the study area, was estimated at 5,000 cfs for the post-Cochiti water years (USBR 2003). For the purposes of modeling channel characteristics in this report, 5,000 cfs will be used as the channel forming flow.

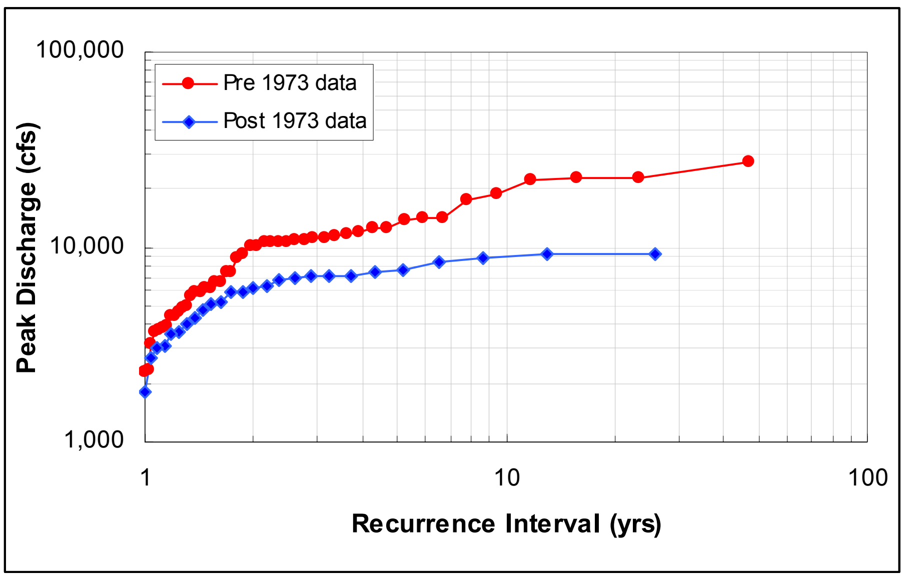

Figure 8: Flood frequency curve for the Rio Grande, using peak discharge data from the USGS Rio Grande gaging station at San Felipe, NM.

2.2 Sub-Reaches Descriptions

The Bernalillo Reach was subdivided into three sub-reaches (Figure 7): sub-reach 1 extends about 1.8 miles downstream from the Bernalillo Bridge, sub-reach 2 is approximately 1.9 miles in length and extends to just upstream of the confluence with Arroyo de la Barranca (CO-32), while sub-reach 3, another 1.6 miles, ends at the Arroyo de las Montoyas confluence. The sub-reach boundaries were determined by changes in slope and current geomorphic observations.

The current channel description, based on 2000-2001 field observations, indicates that the study area is in a state of transition. Sub-reach 1, is a deep, single-threaded channel at low flows (Figure 9) with riffle morphology development. However, the channel form becomes multi-threaded (almost anastomosing) at high flows as the higher elevation side channels flow around the islands (Figure 10). Most of the islands are not inundated during the channel-forming high flows. The bed material is bi-modal, such that both gravel/cobble and sand deposits are found in the active channel (Figure 11).

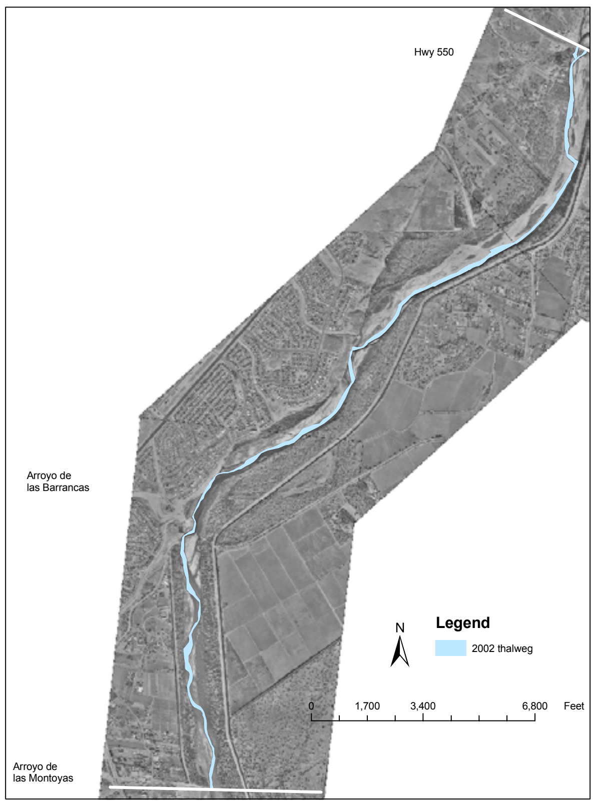

Figure 9: Re-printed thalweg map (Ortiz, 2003), Rio Grande-Bernalillo Bridge Reach, overlain on 2001 aerial photos.

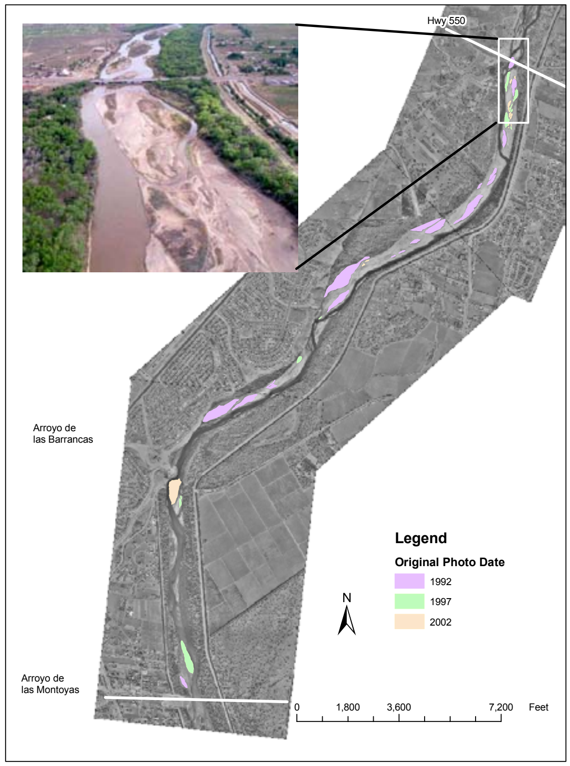

Figure 10: Island locations (R. Ortiz, 2002) and estimated formation dates in the Bernalillo Bridge reach of the Rio Grande, overlain on 2001 photos. Inset photo is looking upstream towards Hwy 550, photo from Bureau of Reclamation, Albuquerque Area Office, River Analysis photo archives, 2001.

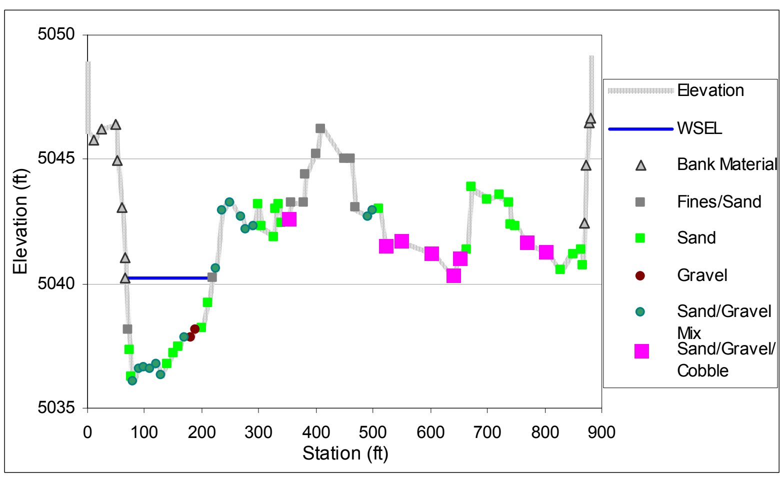

Figure 11: June 2000 cross section data at CO-30, with bed material size data superimposed, Rio Grande, Bernalillo Bridge Reach.

Sub-reach 2 has two dominant morphologies: sub-reach 2a, upstream of CO-31 (Figure 7) is similar to sub-reach 1 with a single-thread morphology and gravel substrate, while downstream of CO-31, sub-reach 2b, has more of a sand bed and braided morphology. Sub-reach 2b appears to be an upstream depositional area caused by Arroyo de la Barranca. The channel bed is mostly sand with small gravel sized sediment. Island development is less than that found in sub-reach 1. Most islands developed in the early 1990s (Figure 10). These islands typically become flooded during the channel-forming high flows.

Sub-reach 3, which is generally a sand bed, appears to be a cross between a braided and an anastomosing channel, as both mid-channel bars and islands split the lower discharges. Short sections of gravel bed exist, especially at confluences with arroyos, otherwise this sub-reach is sand bedded. This sub-reach has the fewest established islands in the study reach; most of these islands developed in the late1990s (Figure 10) and are inundated at high flows.

2.3 Current Channel Dimensions

The current channel cross section data indicate that sub-reach 2b is the smallest channel with the fastest flows (Table 3), while sub-reach 1 has the deepest channels and greatest area and perimeter as estimated in HEC-RAS at 5,000 cfs. Sub-reach 1 is a relatively large channel, with a very deep maximum depth value. A deep maximum depth is consistent with a meandering channel pattern (Figure 12). Sub-reach 2a is similar in physical features to sub-reach 1, however the data indicates a slightly smaller channel with a faster flow. Sub-reach 2b has the smallest overall channel cross section. Consistent with a smaller channel, sub-reach 2b has the largest average depth and fastest water velocity. Sub-reach 3 has cross section features more similar to sub-reach 1, except, this sub-reach has a relatively shallow maximum depth at 5.8 feet. The lack of a deep thalweg is consistent with a braided planform.

Table 3: Reach averaged channel dimensions at 5,000 cfs, Rio Grande, Bernalillo Bridge reach.

Sub-Reach	Length (mi)	Channel Width (ft)	Average Depth (ft)	Max Depth (ft)	W/D (ft/ft)	Velocity (ft/sec)	Channel Area (sq. ft)	Wetted Perimeter (ft)
1	1.97	550	3.1	8.1	180	3.0	1720	570
2	1.77	425	3.8	7.3	110	3.4	1520	420
2a	0.73	500	3.2	7.3	160	3.3	1570	500
2b	1.04	375	4.1	7.2	90	3.4	1490	380
3	1.52	550	3.2	5.8	170	3.0	1670	540
Ave. Reach	5.26	500	3.4	7.2	150	3.1	1640	510

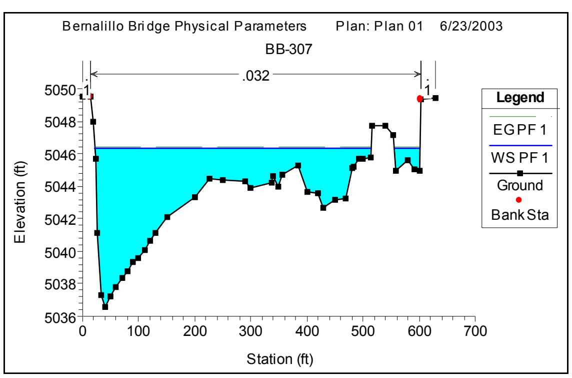

Figure 12: Cross section BB-307 filled with a discharge of approximately 5,000 cfs (HEC-RAS model output) shows both a very deep channel at station 40 and an un-flooded island between the 500-600 stations.. All the cross section figures are located in Appendix A.

Sub-reach 2a has the steepest slopes in the entire reach at just over 0.0015 for an average bed slope (Table 4). Sub reach 2b has the shallowest thalweg slope, a trend common for a depositional zone. As found with the physical cross section data (Table 3), sub-reaches 1 and 3 have similar slopes. Individual slope data shows that the thalweg shallows between cross sections BB-323 and CO-31, thus creating a negative slope at cross section CO-31 (Table 5).

Table 4: Average slope data for each sub-reach – Rio Grande, Bernalillo Bridge Reach.

Sub-Reach	Thalweg Slope	Water Surface Slope	Average Bed Slope
1	0.00088	0.00086	0.00092
2	0.00128	0.00091	0.00120
2a	0.00228	0.00092	0.00152
2b	0.00066	0.00091	0.00099
3	0.00083	0.00091	0.00085
Ave. Reach	0.00101	0.00090	0.00100

Table 5: Slope data for each cross section in the Bernalillo Bridge reach – Rio Grande.

	Thalweg Slope	Water Surface Slope	Average Bed Slope
CO-29	0.00152	0.00107	0.00181
BB-301	0.00147	0.00091	0.00138
BB-307	0.00003	0.00076	0.00020
CO-30	0.00092	0.00083	0.00082
BB-318	0.00077	0.00112	0.00052
BB-323	0.00464	0.00062	0.00309
CO-31	-0.00080	0.00065	0.00003
BB-327	0.00080	0.00093	0.00046
CO-32	0.00102	0.00097	0.00174
BB-340	0.00050	0.00096	0.00011
BB-345	0.00063	0.00085	0.00094
CO-33	0.00140	0.00092	0.00151

2.4 Bed Material Sizes

At the time when Cochiti dam began operations, the Rio Grande in the Bernalillo area was sand bedded (Figure 13), however by the early 1990s, the bed material included measurable amounts of gravel. Bed material data collected in the early 1990s found that although most of the d_{84} grain sizes were in the gravel size range (Figure 13), the median grain size values (d_{50}) were mostly sand and hence probably a sand bed with only some gravel. However, by the late 1990s, the median grain sizes were more consistently gravel indicating a grain size conversion to gravel from sand. Bed material samples taken in 2000 show that gravel is found throughout this reach, and that the main flow channels have become mostly dominated by gravel (Figure 11). The most recent data collection efforts in 2001, focused on collecting sediment data at each of the older CO-lines, as well as at each of the new BB-lines (Table 6). These 2001 bed material data indicate that gravel dominates all but four of the cross sections; however, three of the four cross sections still have gravel sized d_{84} values.

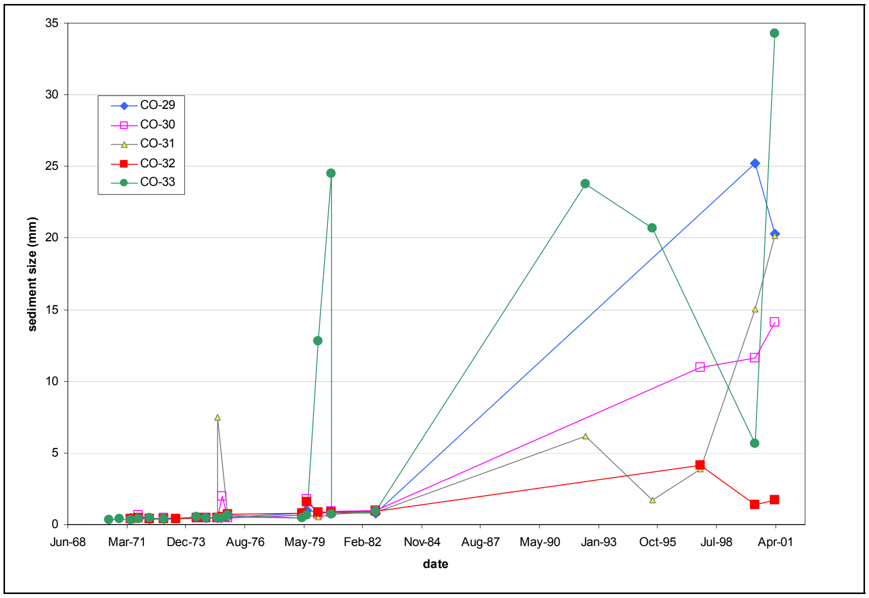

Figure 13: Historic bed material data (d_{84}) in millimeters for the CO-lines, Rio Grande, Bernalillo Bridge area; data collected by USBR contractors.

Table 6: Bed material data (in millimeters) for the Bernalillo Bridge area, Rio Grande; data collected by contract with Tetra Tech Inc. for the USBR.

	Date collected	d_{35}	d_{50}	d_{84}
CO-29	4/11/01	2.85	6.83	20.32
BB-301	4/13/01	5.71	12.72	34.53
BB-307	4/13/01	8.46	18.13	37.21
CO-30	4/11/01	1.11	4	14.14
BB-318	4/13/01	6.90	16.77	54.41
BB-323	4/13/01	5.93	16.00	64.59
CO-31	4/11/01	4.17	7.42	20.14
BB-327	4/13/01	0.83	1.10	3.38
CO-32	4/11/01	0.37	0.48	1.69
BB-340	5/15/01	0.85	1.41	13.96
BB-345	5/15/01	1.00	1.85	9.45
CO-33	4/11/01	4	12.44	34.25

The spatial sediment size data (Table 6) indicates that the grain size is largest upstream, becoming a sand/gravel mixture in the upstream fan of Arroyo de la Barranca, then coarsening again downstream of the arroyo. Large gravel dominates the armor layer (d_{84}) in sub-reach 1 and sub-reach 2a. Even the d_{35} calculated grain sizes in this upstream area are gravel (Table 6). Sediments deposited in the Rio Grande from Arroyo de la Barranca are clearly visible in the 2001 photos as a fan-shaped feature in the Rio Grande channel (Figure 14). Just upstream of this confluence, the size of sediment sampled in the Rio Grande is substantially smaller than that measured further upstream. It is likely that the decrease in sediment size is directly related to this tributary fan development, such that the fan has decreased the transport capacity in the Rio Grande through a reduced stream slope. Downstream of the confluence in sub-reach 3 (CO-32), the size of sediment increases, however, a large portion is sand or smaller sized sediment.

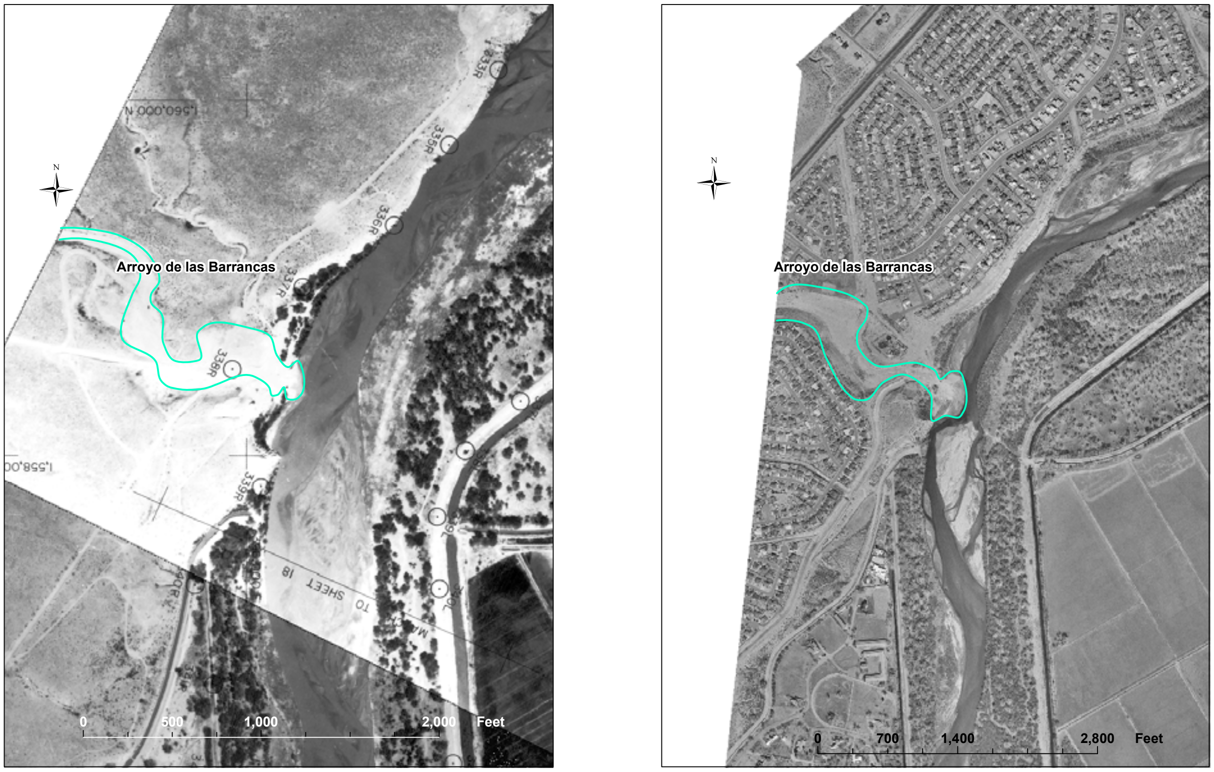

Figure 14: Aerial photos from 1972 (left) and 2001 (right) showing the increased influence on the Rio Grande from the sediment fan of Arroyo de la Barranca. Note the different scales.

Although the sediment size increases downstream of Arroyo de la Barranca (Table 6), the armoring-sediment (d_{84}) is smaller than that found upstream of the confluence. The distribution of sizes in these downstream samples are also more diverse than those found in the samples upstream, such that the median (d_{50}) and d_{35} grain sizes are no longer gravel sized. These data suggest two possible processes present in the downstream site: 1) additional sediment enters the Rio Grande from Arroyo de la Barranca that decreases the sediment size distribution, and/or 2) sediment transport capacity changes downstream (relative to the upstream section with gravel) that allows smaller sediment sizes to deposit along with the larger material (i.e., decrease in channel slope). In either case, the bed material in this section of river is different than found upstream indicating that the channel forming processes are not identical. Ortiz (2002) suggests that downstream of the Arroyo de la Barranca confluence is a transition zone that increases the sediment size as found in the upstream section (e.g., sub-reach 2). These bed material data at least partially supports Ortiz's assertion of a transition zone, however, additional data are warranted.

2.5 Bed Sediment Particle Stability Analysis

Incipient motion calculations allow a cursory assessment of the stability of the channel's bed material. This method assumes that the channel bed is more stable if the calculations indicate a high flow to initially move the channel material and less stable if lower flows move the size of material present on the channel bed. Although there are several methods that assess initial motion of grains on a channel bed, the most simple analytical tool is comparing shear stresses, which is the method employed for this study.

2.5.1 Shear Stress Comparison Methods

A shear stress comparison method (Knighton, 1998) assumes that a grain on the bed of a channel will move only when the overriding pressures of the flow (τ_o) over comes the resistance to motion or the critical shear stress (τ_c) of the particle. Three limitations to this method are: 1) it over estimates the shear stress necessary to initiate mobilization because it ignores lift due to both the velocity differences in the basal laminar flow, and the turbulence or eddying effects that breaks through the basal laminar flow, 2) it ignores grain packing on the channel bed and the effects of grain-grain interaction which could prevent all grain movement if well packed or accelerate movement if exceptionally loose, and 3) the method ignores the influence that the high sand load has on gravel transport (Wilcock et al. 2001, and Wilcock and Crowe 2003). Based on field observations, the bed material in the channel of this reach is loose, and therefore grain packing is not considered a limitation in this study. Unaccounted lift due to velocity differences and turbulence is not addressed nor is the increased transport of gravel due to the high sand load; therefore the results are likely underestimates for the 'true' mobility of the bed material.

Equations:

$\boldsymbol{\tau_o}=\gamma Rs$ (general equation)

γ is the specific weight of water (9.807 kN/m^3 for water at 5C, or 9807 kg/m^{2}s)
R is the hydraulic radius (m)
s is the channel slope (m/m)

$\boldsymbol{\tau_c}=kg(\rho_s-\rho)D$ (Shields equation)

k ranges from 0.03-0.06, 0.045 accepted as a good approximation (Komar, 1988) which is lower than Shields' value of 0.06.
D is grain size (m)
g is gravity (m/s)
ρ_s is density of sediment (2650 kg/m^3)
ρ is density of water (1000 kg/m^3 for water at 5C)

Initial motion calculations were completed for sediment sizes present at each cross section. Physical conditions for six different flows, 2,000 cfs, 3,000 cfs, 4,000 cfs, 5,000 cfs, 7,000 cfs and 10,000 cfs, as determined by the HEC-RAS model were used in the model. Initial motion was determined for both the d_{84} and d_{50} grain sizes present (Table 6).

2.5.2 Bed Sediment Particle Stability Results

Results from the shear stress comparison indicated that the median grains present at nearly all cross sections were mobile between 5,000-7,000 cfs. Model results indicate that over half the cross sections potentially have mobile bed material (d_{50}) at 2,000 cfs (Table 7), which is a flow greatly below the current 2-year recurrence interval flow (Richard 2001, Bullard & Lane 1993, USBR 2003). The cross sections with mobile median bed material are the downstream cross sections which have more sand than gravel present. Between 5,000 cfs and 7,000 cfs, model results indicate that the median bed material at nearly all cross sections is mobile. Overall, these results indicate that flows near the 2-year flow or just over it, mobilize the median bed material in the reach.

Table 7: Estimated mobility of d_{50} grain sizes for the Bernalillo Bridge Reach.

Cross Section	Grain Size (mm)	2000 cfs	3000 cfs	4000 cfs	5000 cfs	7000 cfs	10,000 cfs
CO-29	6.83	yes	yes	yes	yes	yes	yes
BB-301	12.72	no	no	no	no	yes	yes
BB-307	18.13	no	no	no	no	no	no
CO-30	4	yes	yes	yes	yes	yes	yes
BB-318	16.77	no	no	no	no	no	yes
BB-323	16	no	no	no	no	no	no
CO-31	7.42	yes	yes	yes	yes	yes	yes
BB-327	1.1	yes	yes	yes	yes	yes	yes
CO-32	0.48	yes	yes	yes	yes	yes	yes
BB-340	1.41	yes	yes	yes	yes	yes	yes
BB-345	1.85	yes	yes	yes	yes	yes	yes
CO-33	12.44	no	no	no	no	yes	yes

Unlike the median grain sizes, d_{84} grain sizes are mobile in the downstream half of the reach, but not mobile upstream (Table 8). The d_{84} grain size represents the 16th largest grain measured in the sample and are often considered as the grains most likely to form an armor layer. Model results show that d_{84} bed material sizes are mobile at several cross sections with flows less than the 2-year recurrence interval, but that this bed material, at all of the upstream cross sections, is immobile. In fact, the d_{84} grain sizes present at the upstream cross sections appear immobile to flows beyond 10,000 cfs.

Table 8: Estimated mobility of d_{84} grain sizes for the Bernalillo Bridge Reach.

Cross Section	Grain Size (mm)	2000 cfs	3000 cfs	4000 cfs	5000 cfs	7000 cfs	10,000 cfs
CO-29	20.32	no	no	no	no	no	no
BB-301	34.53	no	no	no	no	no	no
BB-307	37.21	no	no	no	no	no	no
CO-30	14.14	no	no	no	no	no	yes
BB-318	54.41	no	no	no	no	no	no
BB-323	64.59	no	no	no	no	no	no
CO-31	20.14	no	no	no	no	no	no
BB-327	3.38	yes	yes	yes	yes	yes	yes
CO-32	1.69	yes	yes	yes	yes	yes	yes
BB-340	13.96	no	no	no	no	no	yes
BB-345	9.45	no	yes	yes	yes	yes	yes
CO-33	34.25	no	no	no	no	no	no

2.5.3 Bed Sediment Particle Stability Summary

1. Median grain sizes at cross sections upstream of CO-31, typically move near the 2-year flows, however the armoring grain sizes (d_{84} sizes) are immobile.
2. Cross sections BB-327 and CO-32, upstream of Arroyo de la Barranca/RRWWTP have smaller sediment (both d_{50} and d_{84}) which is mobile at flows much less than 2-year return flows.
3. Median bed material at cross sections downstream of Arroyo de la Barranca/RRWWTP also move at small flows, however, the larger bed materials (d_{84} sizes) do not typically move until the 2-year recurrence is exceeded.
4. The spatial differences found in the initial motion calculations likely result from 2 distinct processes: 1) arroyo influenced slopes promoting the deposition of smaller sized sediment (cross sections BB-327 and CO-32), and 2) large variability in sediment sizes routed through the system from both upstream and local sources. The supply of sediment likely consists of 3 different sediment sources: 1) an upstream supply of mobile gravel material that moves easily through the channel network (i.e., d_{50} sizes), 2) an upstream supply of very slow-moving gravel/cobble material which may be from the eroding bluffs at the Coronado Monument (i.e., d_{84} sizes), and 3) incoming supply of gravel/sand from Arroyo de la Barranca.

3.0 ESTIMATED FUTURE CONDITIONS

The future conditions of four river characteristics are assessed in this section: sediment supply, sediment size, channel pattern and channel bed elevation. Sediment supply and sediment size are intimately linked therefore they are discussed together. Channel pattern changes and the inception of channel bed incision appear to be co-incident in the upstream section of this reach, hence these two subjects will be discussed together as well.

3.1 Estimated Future Sediment Characteristics

Of the three sources of sediment, upstream supply, tributaries, and erosion of the channel (bed and banks), sediment from only the tributaries is expected to supply sediment in measurable amounts in the future, and that supply is only a fraction of historic sediment supplies. Due to the operations at Cochiti dam, the supply of sediment from distal source (the upstream supply of sediment) is trapped indefinitely in Cochiti reservoir. Since there are no plans to remove Cochiti dam or to create a sediment by-pass, there is no supply of sediment from upstream sources at present nor is expected in the future. The main source of sediment downstream of Cochiti dam is sediment transported to the Rio Grande from arroyos/tributaries. The increase in suspended sediment measured 1993-1995 occurred during particularly stormy years in which the tributaries/arroyos transported abundant sediment to the Rio Grande. Even though an increase in sediment occurred, the effect was temporary, and the magnitude of the supply of sediment was significantly lower than historic levels.

Using 1973-1999 (except 1993-1995) suspended sediment data as an indicator, bed and bank erosion does not supply significant amounts of sediment to the Rio Grande. These sediment data indicate an order of magnitude decrease in suspended sediment. Over time, as in-channel sources continue to erode, the amount of sediment from the bed and banks will diminish, thus decreasing the supply of suspended sediment in the Rio Grande even further.

The bed sediment particle stability results indicated that the gravel beds are stable, while the sand beds are not stable, and will not be stable until they convert to gravel (Tables 9 & 10) for the given flow and sediment regime. Additional transport calculations (Table 9) indicate that the estimated grain size mobile through out the reach is within the gravel range, for the current channel form and shape and at the channel forming flow of 5,000 cfs. These results generally indicate that the channels with unstable beds are generally found downstream of CO-31 in sub-reach 2b and sub-reach 3.

Table 9: Current median grain sizes and the estimated stable grain sizes up to 5,000 cfs for the Rio Grande-Bernalillo Bridge Reach.

Cross Section	Current d_{50} Grain Size (mm)	Current d_{84} Grain Size (mm)	Estimated *Stable* Grain Size (mm)
CO-29	6.83	20.32	15
BB-301	12.72	34.53	10
BB-307	18.13	37.21	10
CO-30	4	14.14	9
BB-318	16.77	54.41	13
BB-323	16	64.59	9
CO-31	7.42	20.14	12
BB-327	1.1	3.38	12
CO-32	0.48	1.69	18
BB-340	1.41	13.96	10
BB-345	1.85	9.45	13
CO-33	12.44	34.25	10

In summary, suspended sediment data indicate that the supply from upstream sources were much greater than the sediment currently delivered by the local tributaries and in-channel erosion. Hence, the supply of sediment will likely remain much lower than historic levels, and may decrease as the in-channel sources are depleted. The sections of channel bed that has not yet converted to a gravel bed will likely convert in the near future, especially since this reach of the Rio Grande appears to be ‘graded’ for a gravel channel bed.

3.2 Estimated Future Channel Elevation and Pattern

Channel incision is expected to continue especially in those locations that are not yet gravel bedded. Channel elevation is a difficult parameter to predict, a combination of channel bed material results with the sediment transport results are used to estimate the most likely future incision conditions. Channel incision is unlikely along the 5 cross sections in which the current median grain size is not mobile during the channel forming flow (Table 10): BB-301, BB-307, BB-318, BB-323 and CO-33. Four other cross sections (CO-29, CO-30, CO-31 and BB-340) could experience a minor amount of bed erosion since the mobile grain size is larger than the median grain size. However in these four locations, the current size of the 'armor' layer is larger than the mobile size which should limit the amount of bed erosion. The most bed erosion is will likely occur in the three remaining cross sections (BB-327, CO-32 and BB-345) where the estimated mobile grain size is larger than both the median grains and the 'armoring' grains.

Table 10: Summary of potential incision for each cross section, Rio Grande-Bernalillo Bridge Reach.

Cross Section	Estimated Channel Elevation Changes
CO-29	Minor amount of incision possible
BB-301	No incision likely
BB-307	No incision likely
CO-30	Minor amount of incision possible
BB-318	No incision likely
BB-323	No incision likely
CO-31	Minor amount of incision possible
BB-327	Significant amount of incision possible
CO-32	Significant amount of incision possible
BB-340	Minor amount of incision possible
BB-345	Significant amount of incision possible
CO-33	No incision likely

Even though portions of this reach are still semi-braided at low flows, the future channel pattern will likely be the full conversion to a single-threaded channel that may have sections of 'island-braiding' as described by Ortiz 2003. At present, sub-reach 1 and sub-reach 2a exhibit this pattern which emerged in the 1990s with a slight meander. This pattern appears stable; however, with continued incision, the high flow channels are expected to become more abandoned until they are no longer accessible by the river. At that point, the channel pattern will become fully single-threaded. Sub-reach 2b and all of sub-reach 3 still has a multiple thalweg pattern. Within this downstream section, small areas have already begun converting as visible by the concentration of flows into one main channel. This conversion is expected to progress until the entire reach is a continuous single-threaded channel.

4.0 CONCLUSIONS

- The Rio Grande flows along a rift valley which has been slowly filling with sediments for millions of years.
- Climate data indicates three distinct precipitation periods during 1942-1999, and that the latest period, 1984-1999 has been the wettest with an average of over 10 in/yr.
- Based on peak discharge records from the Rio Grande USGS gage at San Felipe, the pre-1973 2-year recurring event was just over 10,000 cfs, but only ~6,000 cfs post 1973. In fact, no flows greater than 10,000 cfs have passed San Felipe since 1967.
- The supply of sediment has decreased significantly.

- The general channel location was 'set' during the channelization activities in the early 1930's.
- Current channel descriptions are:
  - Sub-reach 1 is a deep, single-threaded channel at low flow, with a bi-modal sediment size distribution (sand and gravel), with a riffle environment. High flow morphology includes a partial anastomosing pattern.
  - The upstream half of sub-reach 2 is similar to the morphology and sediment patterns present in sub-reach 1, but with only a slightly sinuous thalweg at low flow.
  - The downstream half of sub-reach 2 has a braided morphology, dominated by sand and small gravel. This section of river bed is the upstream fan of Arroyo de la Barranca.
  - Sub-reach 3 is in transition from low-flow braided to a slightly meandering pattern, with a bi-modal sediment size distribution of sand and gravel. This sub-reach has more sand-sized sediment than measured in either of the sub-reaches.
- Most islands in the Bernalillo Bridge reach were initially formed prior to 1992.
- Sub-reach 2 has the smallest average channel cross section, has the greatest slope and has the fastest estimated velocity.
- Gravel sized sediment first appeared in abundance in the 1992 bed material samples.
- At present, gravel has been sampled in every sub-reach, however, only sub-reach 1 has a channel bed that is fully gravel.
- Initial motion calculations indicate that the median bed material is typically mobile for channel forming or greater flows, while the armor layer (d_{84} grain sizes) is not mobile in the sub-reach 1 and the upstream half of sub-reach 2.
- A continued low supply of suspended sediment is expected.
- The sediment size found on the channel bed is expected to increase in most of sub-reach 2 and sub-reach 3.
- As the sediment size increases in sub-reach 2 and 3, incision is expected until the bed material is no longer coarsening.
- The channel pattern is expected to continue to convert towards a meandering pattern from the braided morphology.

5.0 LITERATURE CITED

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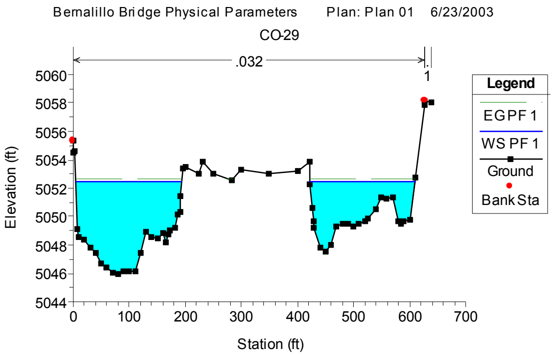
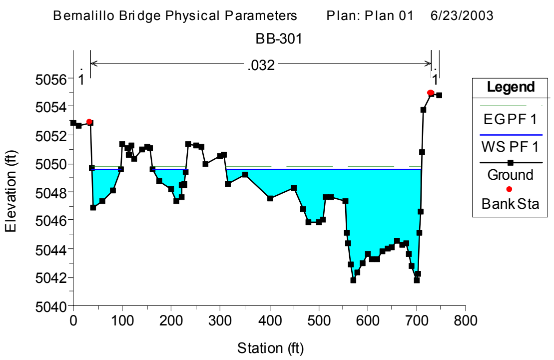
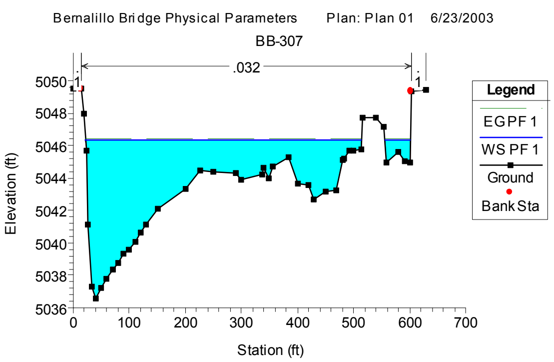
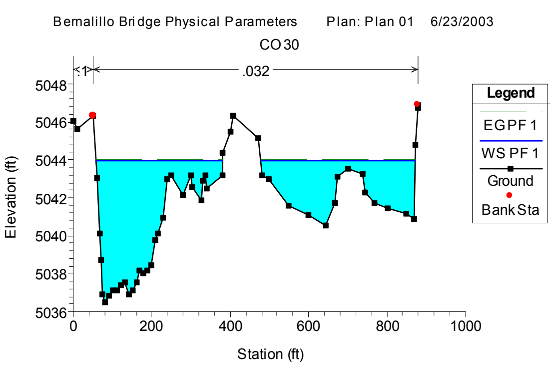
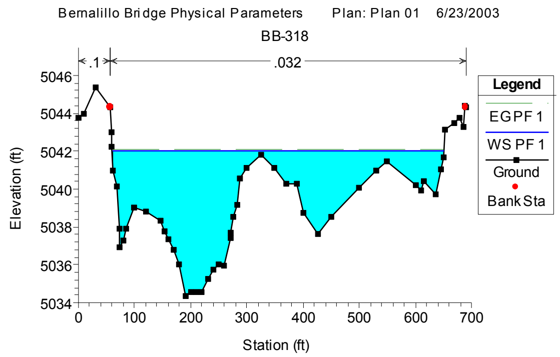
APPENDIX A – Cross Sections filled with 5,000 cfs – Results from HEC-RAS







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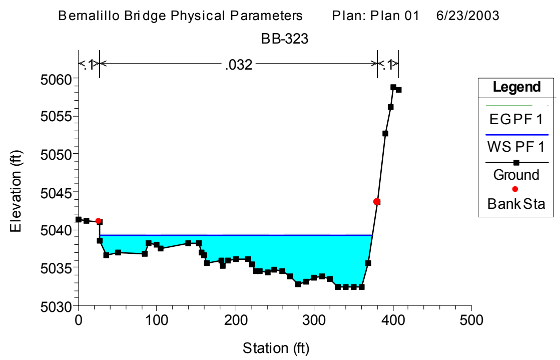
Ground
Bank Sta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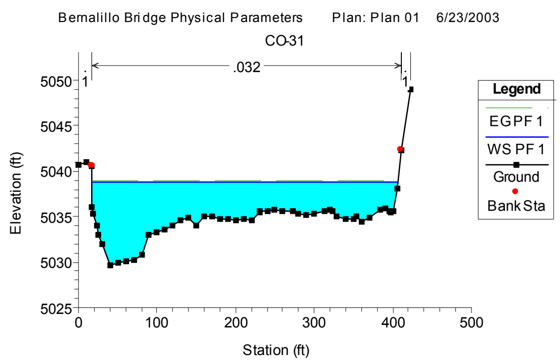
Bank Sta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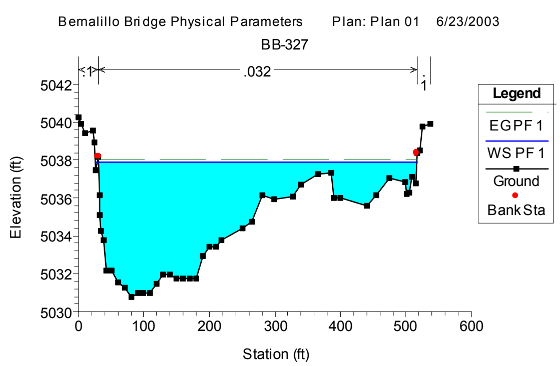
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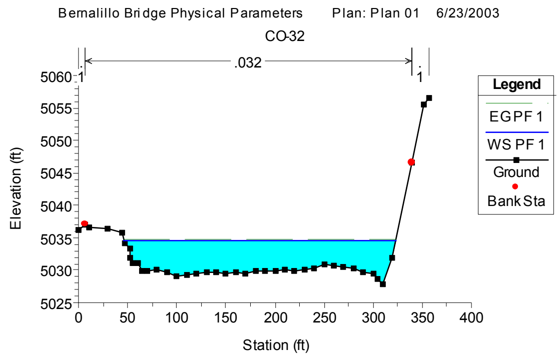
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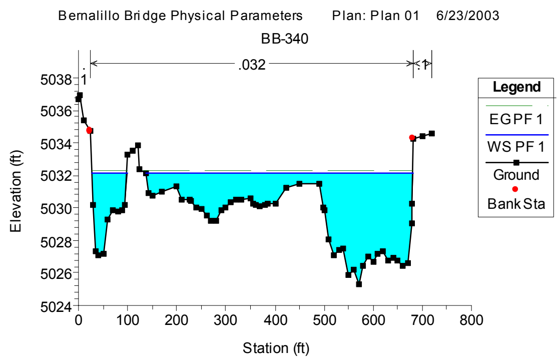
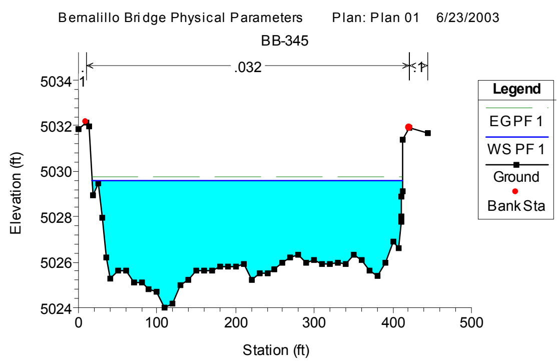
Ground
Bank Sta


Bernalillo Bridge Physical Parameters Plan: Plan 01 6/23/2003
BB-340
.032
Elevation (ft)
Station (ft)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta


Bernalillo Bridge Physical Parameters Plan: Plan 01 6/23/2003
BB-345
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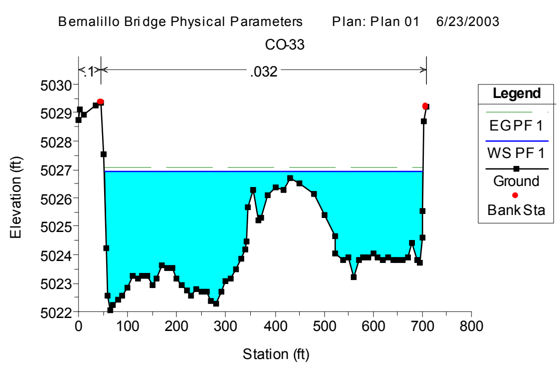
Elevation (ft)
Station (ft)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta


Bernalillo Bridge Physical Parameters Plan: Plan 01 6/23/2003
CO-33
.032
Elevation (ft)
Station (ft)
Legend
EG PF 1
WS PF 1
Ground
Bank Sta